Mechanical and Electrical Systems on Dam Gates

Best Practices in Dam and Levee Safety
Risk Analysis
Part G
Chapter G-4

June 2017

US Army Corps of Engineers®

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

DEPARTMENT OF ENERGY
FEDERAL ENERGY REGULATORY COMMISSION

TVA

Objectives

- Show how Mechanical and Electrical components on gates affect risk

- Show how to calculate Probability of Failure of components on gates

- Show how a systems probability of failure is calculated using Fault Tree Analysis

- Demonstrate a fault tree analysis

Problem
Aging Mechanical & Electrical Systems

What risks are involved with operating gates at a our structure?

Issue 1. Will the gates open or close when needed?

Issue 2. Is there a way to predict if the gates will operate when needed?

Issue 3. What are the consequence if the gates don't operate?

Risk =   Probability of X Consequence of
Component   Component Failure
Failure.

"We also Want to Know"

How Does failure of Mechanical or Electrical Components Affect the Overall Projects Risk Assessment?

# How Mech or Elect Failures affect Risk "Simple Examples"

- If a spillway gate does not operate during a flood event it can cause overtopping of the structure leading to failure.

- If power fails at a project all operation of gates fail, thus increasing the risk of loading on the dam or even overtopping.

- If service gates cannot raise, winter draw down cannot occur thus increasing risk of flooding do to spring rains.
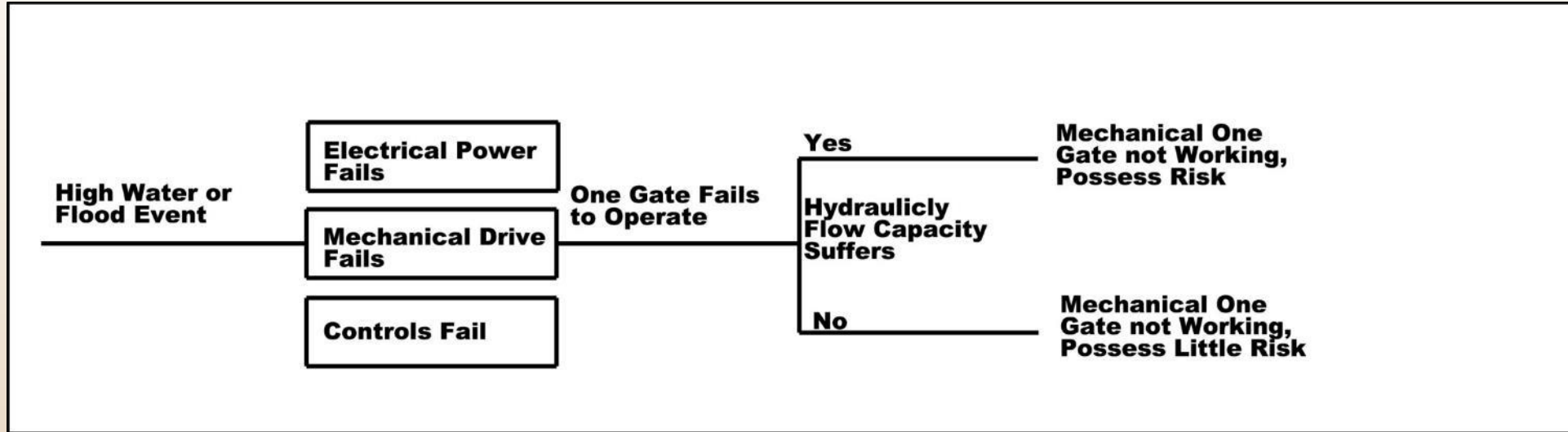
Where does Mechanical or Electrical gate failure fit into the event tree of a project to predict overall Risk?
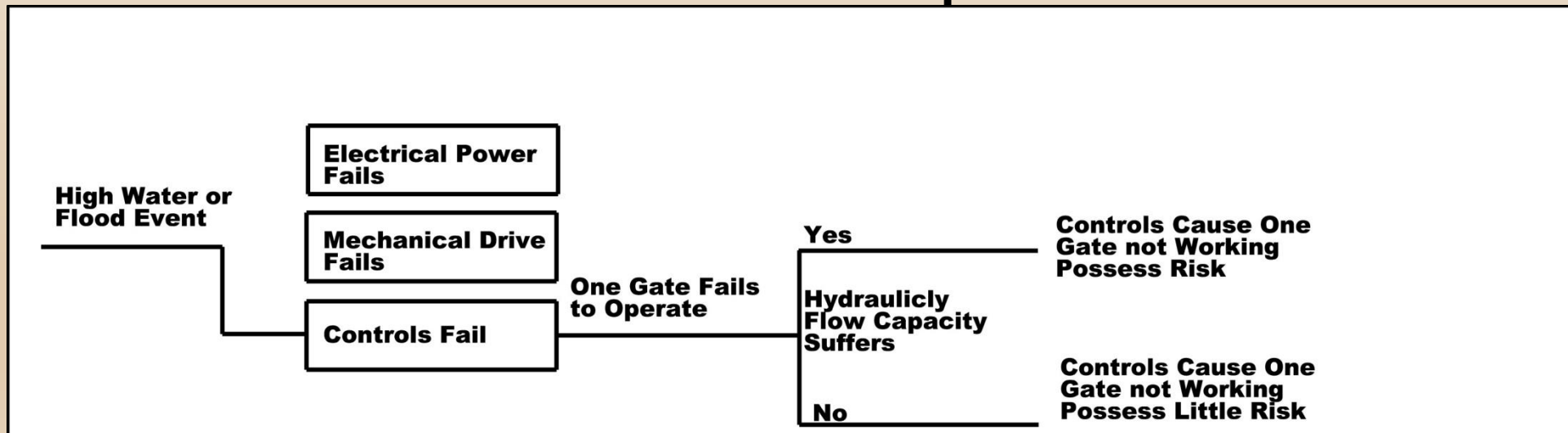
Simple Event Tree

Electrical Power Fails
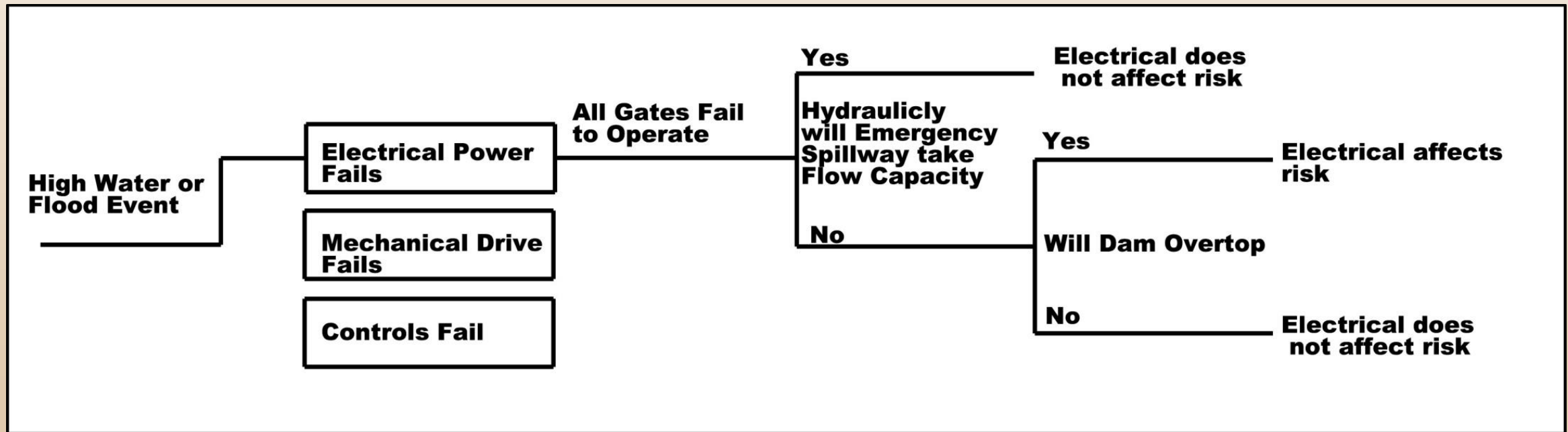
Mechanical Drive Fails to Open Gate

Controls Fail to Open Gate

Predicting/Calculating the Probability of Failure of Dam Components

There are two ways of predicting Probability of Failure

* **Expert Elicitation**
* **Statistical Formulas**

Weibull Distribution Formula

$$R(T) = e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}}$$

R(T) = Reliability
T = Time
γ = Location Parameter
β = Shape Parameter
η = Characteristic Life
e = 2.718

The Weibull distribution is one of the most widely used lifetime distributions in reliability engineering.

Weibull Distribution was invented in 1937 by Swedish born, Waloddi Weibull. Its used by majority of industrial manufacturing industries throughout the world.
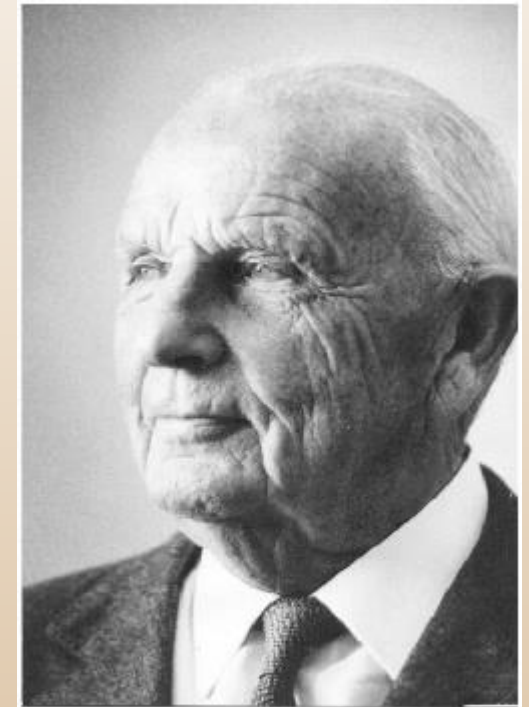
Waloddi Weibull 1887-1979

Problem with the traditional Weibull Formula

It doesn't take into account durations of time when a gate is not in use.

Example: Dam gates that are operated only once a month or once a year.

Solution: The Dormant - Weibull Formula

$$Q_n = 1 - \left(e^{\left(\frac{(n-1)(t)-\gamma}{\eta}\right)^{\beta}}\right)\left(e^{-\left(\frac{n(\tau)-\gamma}{\eta}\right)^{\beta}}\right)$$

Q_n = Probability of Failure over the entire interval n
η = Characteristic Life Parameter
β = Shape Parameter
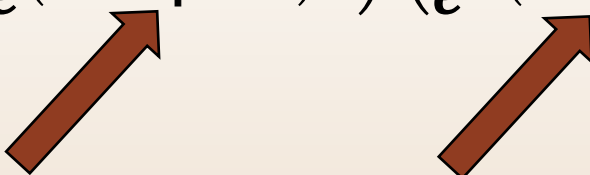γ = Location Parameter
τ = **Inspection Interval or time since last operated**
n = Number of times the component operated in its life.

1st Key Element in the Formula
η = Characteristic life

$$Q_n = 1 - \left(e^{\left(\frac{(n-1)(t)-\gamma}{\eta} \right)^{\beta}} \right) \left(e^{-\left(\frac{n(\tau)-\gamma}{\eta} \right)^{\beta}} \right)$$

Definition: The characteristic life is the point in time when we could expect 63.2% of the components under study to have failed.

Example: Its determined that the characteristic life of a component is 25 years, then you would expect to have 63 of 100 components fail by that time in history.

Characteristic life is traditionally gathered through testing of thousands of samples.

The Corps has gone through a rigorous data search of its inventory of dams and compiled a list of how many and how long its mechanical and electrical component have lasted in real world applications. This data has been placed on a weibull curve to determine the characteristic life of its components.

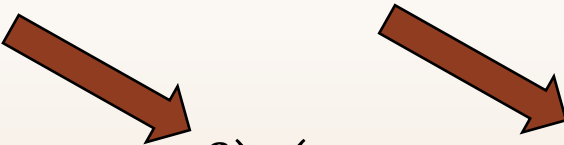# Probability of Failure Weibull Curve for an Electric Motor Determining (Characteristic Life)

Weibull Curve for Electric Motor

63.2 %
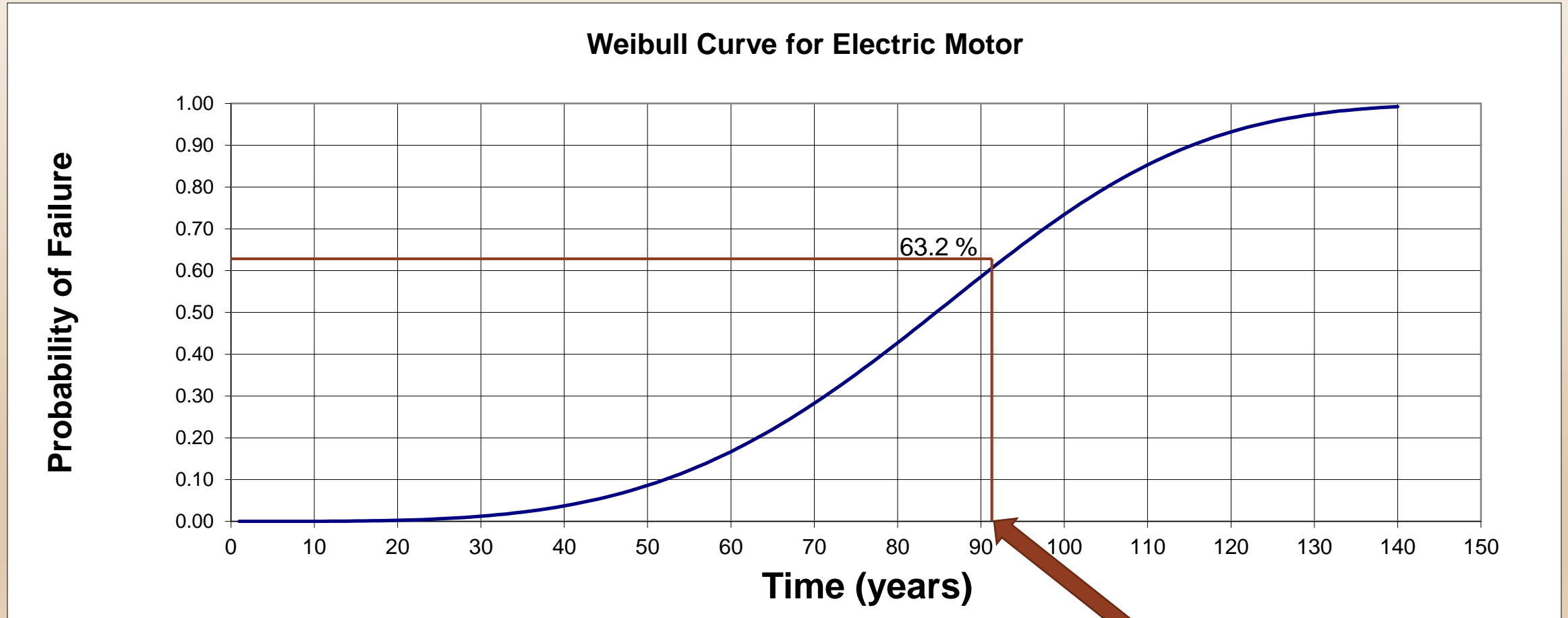
Characteristic Life (93) Years

2ⁿᵈ Key Element in the Formula

2nd Key Element in the Formula

β = Beta Shape Parameter

$$Q_n = 1 - \left(e^{\left(\frac{(n-1)(t)-\gamma}{\eta}\right)^{\beta}}\right)\left(e^{-\left(\frac{n(\tau)-\gamma}{\eta}\right)^{\beta}}\right)$$

β < 1   Implies quality problems or insufficient "Burn In". Usually associated with beginning of a components life.

β = 1   Random failures or failures independent of time in service.

β > 1   Wear out failures at a definite or predictable end of life. Typically age related due to service conditions such as corrosion, wear, or fatigue cracking.

The Corps uses a combination of Beta Shape Parameter factors from ETL 1110-2-560, dated 30 June 2001, and the statistical data it has collected on components.
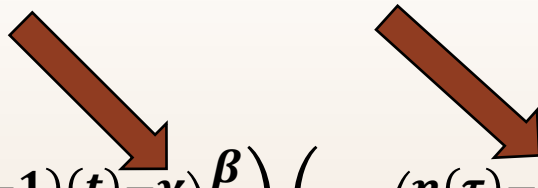
Probability of Failure Weibull Curve for an Electric Motor Determining (Beta Shape Parameter)
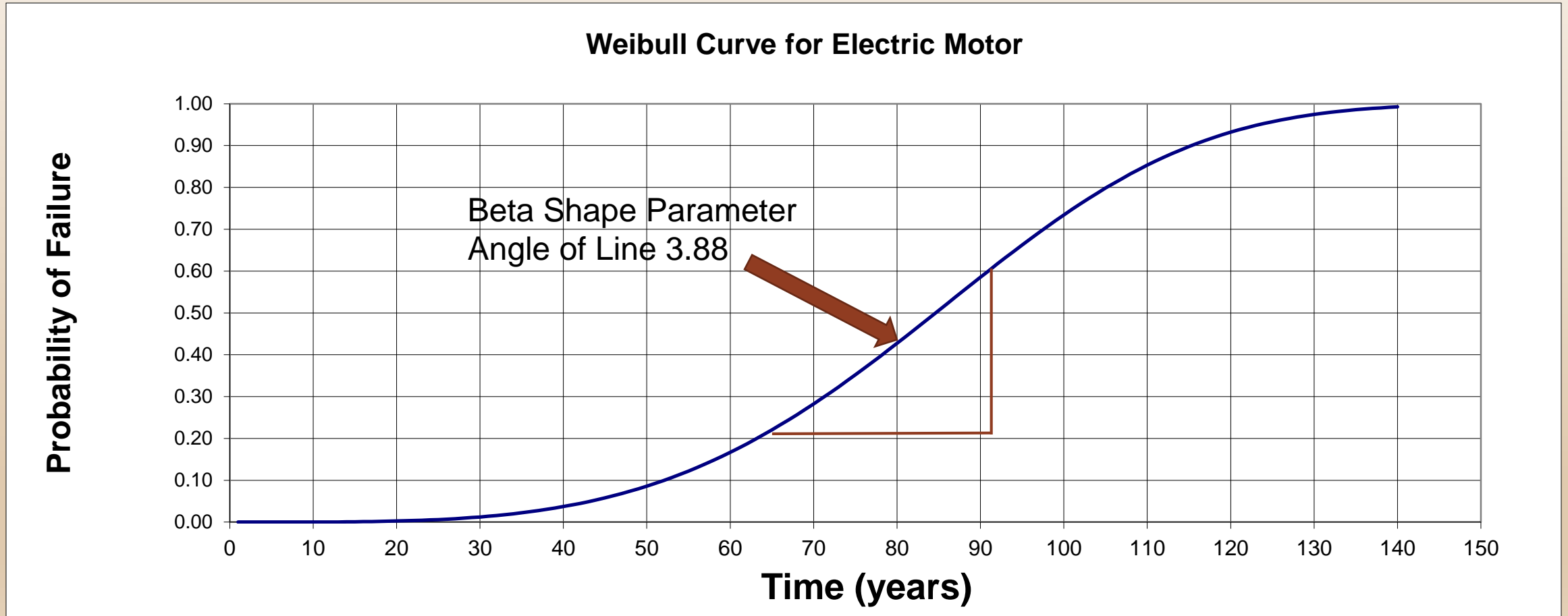
3rd Key Element in the Formula
γ = Location Parameter

$$Q_n = 1 - \left(e^{\left(\frac{(n-1)(t)-\gamma}{\eta}\right)^{\beta}}\right)\left(e^{-\left(\frac{n(\tau)-\gamma}{\eta}\right)^{\beta}}\right)$$

γ = Location Parameter is the difference in years between when the component was originally installed and when it was replaced.

Example: If a component was originally installed in 1965 and was replaced in 1995 the location parameter would be.

1995 – 1965 = 30 years

If the component is original then the location parameter = 0.

4th Key Element in the Formula
t = Inspection Interval

$$Q_n = 1 - \left(e^{\left(\frac{(n-1)(t)-\gamma}{\eta}\right)^{\beta}}\right)\left(e^{-\left(\frac{n(\tau)-\gamma}{\eta}\right)^{\beta}}\right)$$

τ = Inspection Interval. Time in (years) between when the component was last inspected or operated properly to present.

Example: A component was last operated 1 month ago.

τ = 1 month/12 months per year = .0833

Final Results

A formula which predicts a components probability of failure as of this year.

Example: A 50 year old electric motor with a characteristic life of 93 years which was last operated 1 month ago in a normal environment would have a probability of failure of .06% this year.

$$Q_n = 1 - \left(e^{\left(\frac{(600-1)(.083)-0}{93}\right)^{3.88}}\right)\left(e^{-\left(\frac{600(.083)-0}{93}\right)^{3.88}}\right) = .06\%$$

We Want More

Knowing the probability failure of a individual components is good, but we want to know what the systems probability of failure is.

To find the solution the Corps relies on a fault tree analysis program.

The Corps reviewed up to a halve dozen types of software packages which performed fault tree analysis.

Isographs, Fault Tree software was establishes as the superior program for ease of operation and usefulness to the Corps.

Fault Tree Analysis

Or Gate Formula:

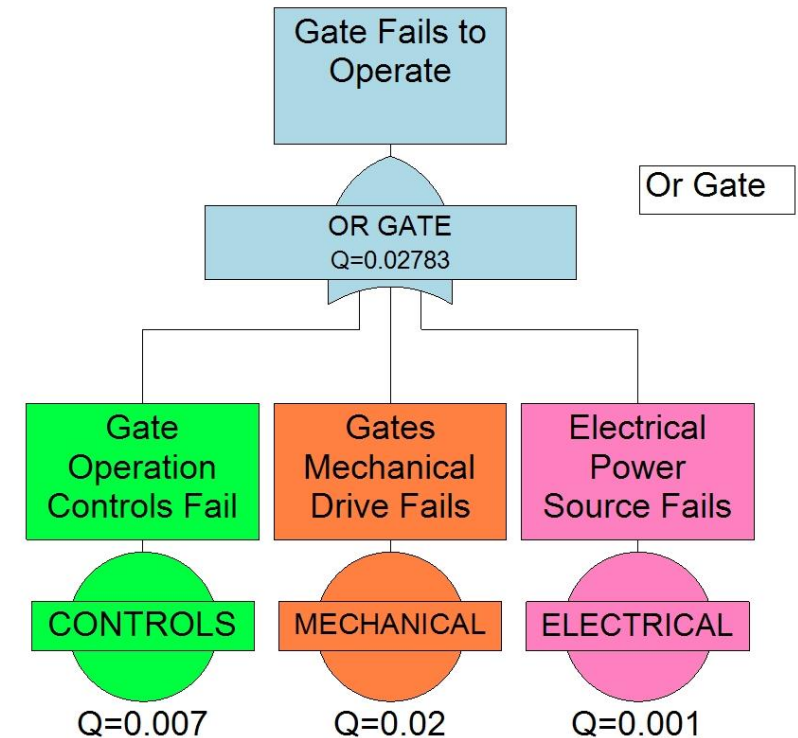This is known as the addition law for independent non-exclusive events.

OR Gate Q = (Input1_Q + Input2_Q + Input3_Q) – (Input1_Q * Input2_Q) – (Input1_Q * Input3_Q) – (Input2_Q * Input3_Q) + (Input1_Q * Input2_Q * Input3_Q)

Example: Q = (.007 + .02 + .001) – (.007* .02) – (.007* .001)- (.02 * .001) + (.007 * .02* .001) = .02783

Probability of Failure to Operate Gates

US Army Corps of Engineers
Dam & Levee Safety
Risk Management Center

Gate Fails to Operate

OR GATE
Q=0.02783

Or Gate

Gate Operation Controls Fail — CONTROLS — Q=0.007

Gates Mechanical Drive Fails — MECHANICAL — Q=0.02

Electrical Power Source Fails — ELECTRICAL — Q=0.001

Fault Tree Analysis

And Gate Formula:

And Gate Q = Input1_Q * Input2_Q
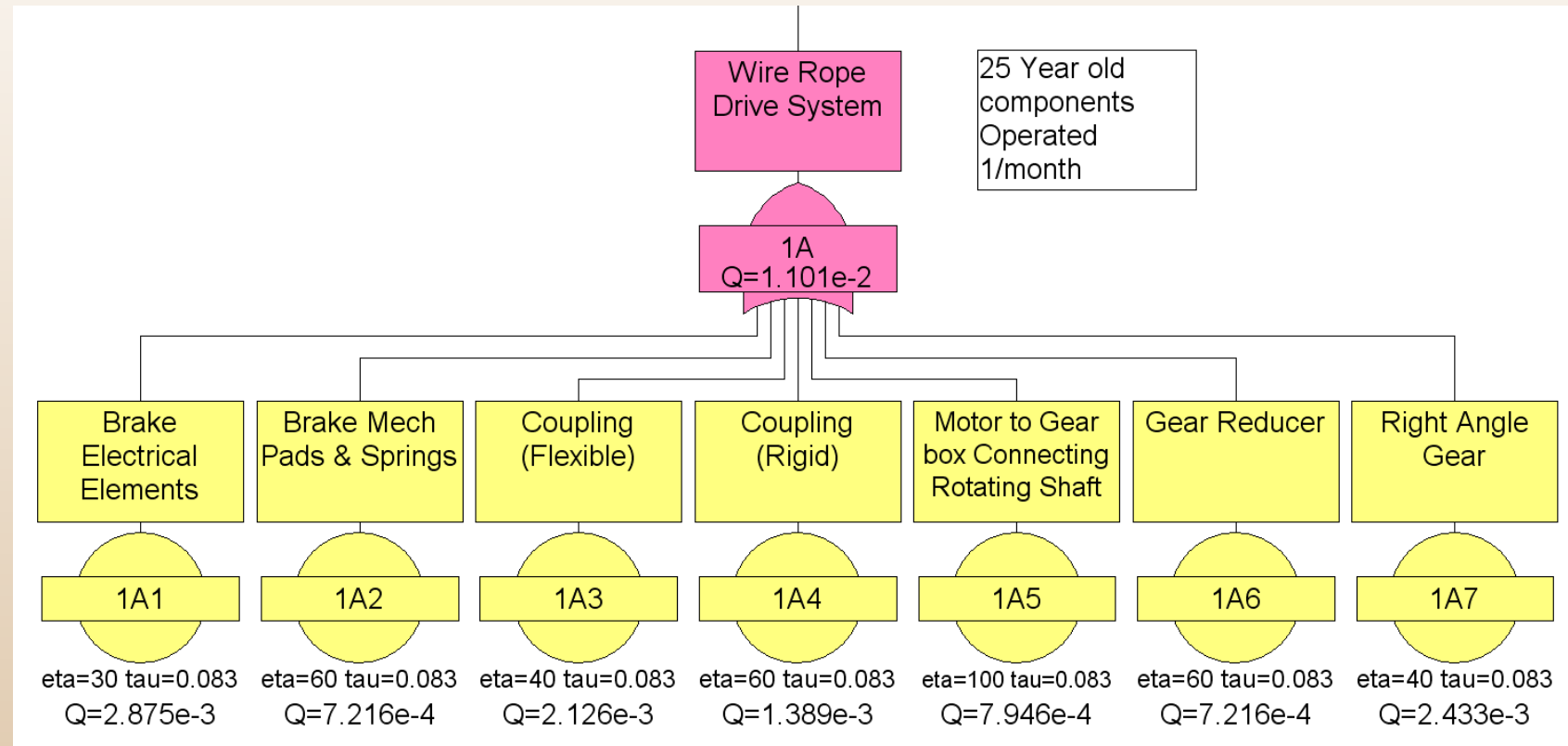
Example: Q = .02 X .01 = .0002
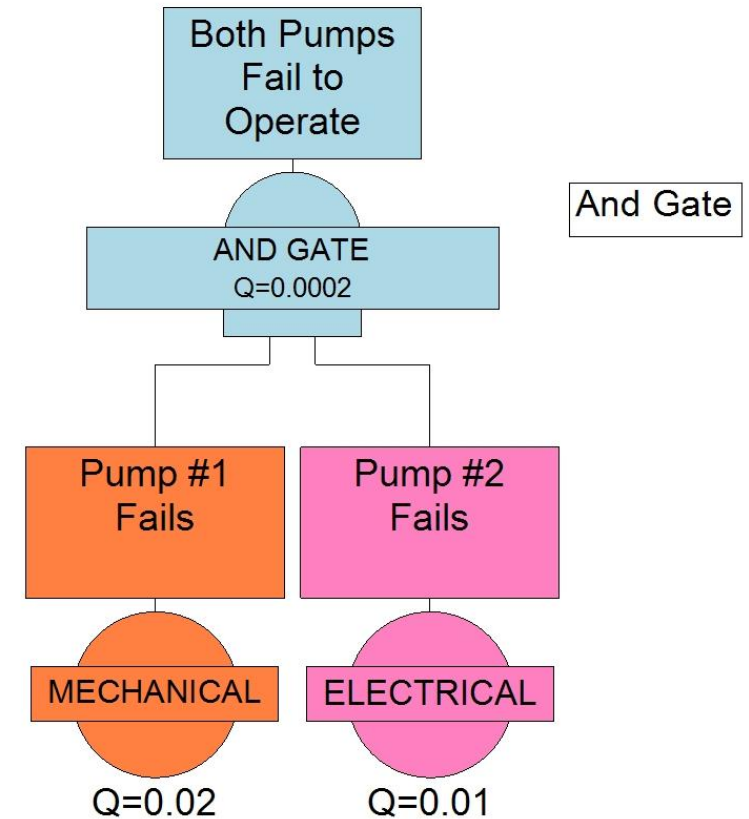
Fault Tree Analysis

Example of a simple wire rope drive systems probability of failure using Fault Tree Analysis.

Eta = Characteristic Life of Component
Tau = Inspection interval
Q= Probability of failure results

Wire Rope Drive System

25 Year old components Operated 1/month

1A
Q=1.101e-2

Brake Electrical Elements	Brake Mech Pads & Springs	Coupling (Flexible)	Coupling (Rigid)	Motor to Gear box Connecting Rotating Shaft	Gear Reducer	Right Angle Gear
1A1	1A2	1A3	1A4	1A5	1A6	1A7
eta=30 tau=0.083 Q=2.875e-3	eta=60 tau=0.083 Q=7.216e-4	eta=40 tau=0.083 Q=2.126e-3	eta=60 tau=0.083 Q=1.389e-3	eta=100 tau=0.083 Q=7.946e-4	eta=60 tau=0.083 Q=7.216e-4	eta=40 tau=0.083 Q=2.433e-3

Example of a Simple Fault Tree for a Flood Control Gate

Note: The math can get very complicated !!!!

Fault Tree Analysis Demonstration Time

The Isograph Reliability Workbench software demonstrating a typical probability of failure of a dam gate and a demonstration of predicting Probability of failure of a automobile.

Note: There are other vendors of fault tree software. Isograph, Reliability Workbench, is just one such software package.